International Journal of Mechanical and Production Engineering Research and Development (IJMPERD)
ISSN(P): 2249-6890; ISSN(E): 2249-8001
Vol. 9, Issue 3, Jun 2019, 713-720

Original Article

OPTIMIZATION OF PROCESS PARAMETERS IN HARD TURNING OF OIL HARDENED NON SHRINKABLE STEEL USING PVD COATED CERAMIC INSERT

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ABSTRACT

Materials with hardness more than 45 HRC are widely used in the manufacturing segments. To attain the prerequisite surface finish, industries rely on conventional grinding process. Elimination of this time intense procedure has become the need of the situation. Recent developments in manufacturing industries led to hard turning which gratify this requirement. In this study, turning of oil hardened non-shrinkable steel with PVD TiN coated ceramic insert is investigated. Optimizations of process parameter like cutting speed, feed and depth of cut resulting in better surface finish and material removal rate are established. Most desirable parameter values are projected by using grey relational analysis supported by Taguchi's L27 orthogonal array and analysis of variance.

KEYWORDS: ANOVA, GRA, Hard Turning, Material Removal Rate, PVD TiN Coated Ceramic Insert & Surface Finish

Received: Mar 23, 2019; **Accepted:** Apr 13, 2019; **Published:** May 10, 2019; **Paper Id.:** IJMPERDJUN201979

1. INTRODUCTION

Modern time industries adopt ground breaking methods to compete the challenges that arise in manufacturing arena. One of such area is the turning of hardened steels. Turning of materials having hardness more than 45HRC is termed as hard turning, which replaces the conventional grinding process to get the required finish. Oil Hardened Non-Shrinkable steels are widely used in most of the cutting tool and measuring tool industries. When required strength, hardness and wear resistance are not attained by other steels, oil hardened non-shrinkable steels finds its place. The traditional procedure of turning hardened steels is shown in Figure 1.

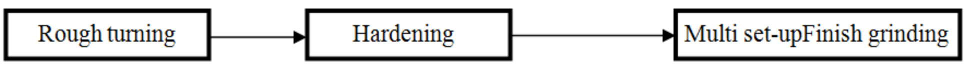

Figure 1: Conventional Method

Trading time consuming grinding process with hard turning increases productivity and yields great savings of cost and time[1-3]. When applied to complex contours, hard turning could result in massive savings in cost[4]. Also grinding operation confines the machining work piece profile to smaller area. While hard turning, overcomes this problem to a prodigious extent. Hard turning replaces the final multi set-up finish grinding with

single set-up hard turning, hence abundant time is saved. The procedur of hard turning is shown in the Figure 2.

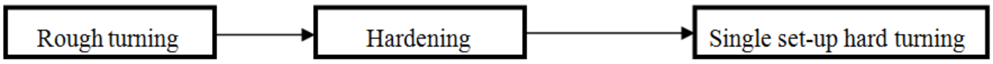

Figure 2: Hard Turning

One of the foremost quality characteristics required of all machining processes is surface roughness. Surface roughness is the main criteria in close fit components, friction between contact bodies etc. Also fatigue life of machined parts reduces due to poorer surface finish i.e., higher surface roughness values. Industries, also strive hard to maximize the material removal rate in order to increase their productivity. Different materials need different cutting parameter values to attain this objective.

Davim and Figueira[5] evaluated D2 steel hard turning with ceramic tools and concluded surface roughness is influenced by feed rate. D'Addona and sunil J Raykar [6] analyzed hard turning of OHNS steel for surface roughness and stated that feed is the utmost significant parameter followed by depth of cut and type of insert. SudhansuRanjan et al[7] made experimental investigations on the machinability of hardened AISI 4140 steel with TiN coated ceramic tool and observed that feed rate affected the surface roughness to the greater extent. The author also stated that lower feed rate and higher cutting speed generated thin chip, resulting in superior surface finish.

F.Puh et al [8] investigated turning of AISI 4142 hardened steel with 55HRC with PCBN insert and stated that feed rate (56.736%) as the most significant factor influencing surface roughness and by depth of cut (41.86%) as the next important significant factor. Cutting speed has very little effect on surface roughness. Many researchers in their studies also confirmed that the most significant factor affecting surface roughness as feed rate[9-11].

Having the most of the prerequisite properties such as high hot hardness, amplified wear resistance and chemical inertness, alumina based ceramic tools are best suited for hard turning except for its brittleness. Extremely brittle nature of ceramic tools limits its application. TiN, Ti(C, N), TiC, (W, Ti)C, TiB, SiCp coated alumina based ceramic tools overcome this barrier [12 – 15].

Selection of cutting fluids become one of the foremost criteria in choosing cutting conditions due to the arising global awareness on safe environment and health issues. To avoid health and environmental hazards, dry machining or near dry machining attracts attention of manufacturers. Cost of coolant acquisition, disposing and cleaning compelled manufacturers to shift from flooded wet machining to dry machining [16]

In this study, experimentation of hard turning of oil hardened non-shrinkable (OHNS) steel with TiN PVD coated ceramic insert is done with Taguchi's L27 orthogonal array. Identifying the significant factors using analysis of variance and process parameters for optimum surface roughness and MRR are estimated using grey relational analysis.

2. EXPERIMENTAL STUDIES

2.1 Work Piece

Oil hardened non-shrinkable(OHNS) steel is a type of cold worked tool steel, used in measuring instruments such as gauges, master tools, drawing dies, punches etc. Chemical composition of OHNS cold worked tool steel is given in Table 1.

Table 1: Chemical Composition of Oil Hardened Non-Shrinkable Steel

Elements	C	Mn	Si	Cr	Ni	W	V	Cu	P	S	Fe
Weight (%)	0.85 – 1.00	1.00 – 1.40	0.50	0.40 – 0.60	0.30	0.40 – 0.60	0.30	0.25	0.03	0.03	balance

Work pieces are cut to the required size and heat treated to 62HRC.

2.2 Tool

PVD coated aluminium oxide and titanium carbonitride composite ceramic insert with ISO designation codeTNGA160408T01020 is used.

2.3 Surface Roughness

The main component of surface roughness arithmetic mean roughness, Ra is measured with Surftest201 of Mitutoyo make for each experimental run. The measurements are taken at 3 positions 120 degrees apart with 8 mm cut-off length. The average of the three values measured is taken for analysis.

2.4 Material Removal Rate(MRR)

Material removal rate is calculated as follows:

$$\text{MRR} = \frac{(Weight\ before\ machining - weight\ after\ machining)}{Density\ x\ time\ taken}\ \text{mm}^3/\text{sec.} \quad (1)$$

3. DESIGN OF EXPERIMENTS

Three factors cutting speed in rpm, feed in mm/rev, and depth of cut in mm are considered for experiments. All factors are investigated under 3 levels using L27 Taguchi's orthogonal array. Cutting parameter values for the three levels are shown in the Table 2.

Table 2: Input Parameters with 3 Levels

Factors	Unit	Level 1	Level 2	Level 3
Cutting speed	rpm	1200	1500	1800
Feed	mm/rev	0.02	0.05	0.08
Depth of cut(DOC)	mm	0.2	0.45	0.7

Table 3: Experimental Results for Surface Roughness (Ra) and Material Removal Rate (MRR)

Sl. No	SPEED rpm	FEED mm/rev	DOC Mm	Weight in 'g'		Time sec	Ra mm	MRR mm^3/sec
				Before	After			
1	1200	0.02	0.20	231	222	79	0.214	14.5441
2	1200	0.02	0.45	235	222	80	0.221	20.7456
3	1200	0.02	0.70	234	215	79	0.214	30.7042
4	1200	0.05	0.20	234	226	32	0.190	31.9163
5	1200	0.05	0.45	231	219	33	0.240	46.4236
6	1200	0.05	0.70	235	217	32	0.292	71.8116
7	1200	0.08	0.20	236	228	22	0.322	46.4236
8	1200	0.08	0.45	231	219	22	0.482	69.6355
9	1200	0.08	0.70	232	214	21	0.681	109.427
10	1500	0.02	0.20	235	227	63	0.202	16.2114
11	1500	0.02	0.45	230	218	62	0.201	24.7094
12	1500	0.02	0.70	235	218	64	0.176	33.9110
13	1500	0.05	0.20	237	228	26	0.178	44.1917

Table 3: Contd.,								
14	1500	0.05	0.45	234	221	28	0.326	59.2730
15	1500	0.05	0.70	234	216	27	0.312	85.1100
16	1500	0.08	0.20	233	225	20	0.412	51.0660
17	1500	0.08	0.45	230	218	19	0.421	80.6305
18	1500	0.08	0.70	232	215	19	0.601	114.227
19	1800	0.02	0.20	230	222	53	0.162	19.2702
20	1800	0.02	0.45	234	222	52	0.166	29.4612
21	1800	0.02	0.70	233	216	53	0.162	40.9492
22	1800	0.05	0.20	237	228	23	0.166	49.9559
23	1800	0.05	0.45	231	219	23	0.274	66.6078
24	1800	0.05	0.70	230	213	22	0.232	98.6502
25	1800	0.08	0.20	231	223	14	0.412	72.9514
26	1800	0.08	0.45	230	218	13	0.328	117.845
27	1800	0.08	0.70	238	220	14	0.611	164.141

4. ANALYSIS OF VARIANCE

Analysis of variance (ANOVA) is used to find the significant factors that influence the surface roughness and material removal rate. The analysis of variance is done with 95% confidence level. The results of analysis of variance for surface roughness and material removal rate are shown in Table 4 and Table 5 respectively. In the table SS, DOF, MS represents sum of squares, degrees of freedom and mean square respectively.

Table 4: ANOVA for Surface Roughness

SOURCE	SS	DOF	MS	F(cal)	F-Value	%Contribution	P – Value	Conclusion
SPEED	0.008083	2	0.004041	0.82	3.49	1.41	0.454	Insignificant
FEED	0.407347	2	0.203673	41.42	3.49	71.11	0.000	Significant
DEPTH OF CUT	0.059045	2	0.029522	6.00	3.49	10.31	0.009	Significant
ERROR	0.098356	20	0.004918			17.17		
TOTAL	**0.57283**	**26**				**100**		

Table 5: ANOVA for MRR

SOURCE	SS	DOF	MS	F(cal)	F(tab)	%Contribution	P – Value	Conclusion
SPEED	2772	2	1386.0	7.30	3.49	7.83	0.004	Significant
FEED	19772	2	9885.9	52.03	3.49	53.82	0.000	Significant
DEPTH OF CUT	9074	2	4536.8	23.88	3.49	25.62	0.000	Significant
ERROR	3800	20	190.0			10.73		
TOTAL	**35417**	**26**				**100**		

5. GREY RELATIONAL ANALYSIS(GRA)

Relationships between factors in complex multivariate system are uncertain, leading to grey situation. In such ambiguous condition grey relational analysis is one of the best known methods in visionary. Grey relational analysis is the most significant part of grey theory system and was developed by Professor Deng in 1982. Available unclear information is transformed to complete information by the principle from black (no information) through grey(less information) to white (full information) [17]. Grey relational analysis compensates any shortcomings in the statistics [18].

The grey relational grade emphasizes the degree of influence exerted by the comparability sequence over the reference sequence. Comparability sequence having more important than other comparability sequence to the reference sequence will have high grey relational grade. The grey relational grade sequence is ranked to know which experimental run gives the best result.

Grey relational calculations are done and given in the table 6.

- GRGC – Grey relational generation calculation.
- DSGC – Deviation sequence generation calculation.
- GRCC – Grey relational co-efficient calculation.
- GRG – Grey relational grade calculation.

Table 6: Grey Relational Calculation

Sl.No	GRGC		DSGC		GRCC		GRG	RANK
	Ra	MRR	Ra	MRR	Ra	MRR		
Reference Sequence(X_0)	**1.0000**	**1.0000**	**1.0000**	**1.0000**	**1.0000**	**1.0000**		
1	0.8998	0.0000	0.1002	1.0000	0.8331	0.3333	0.6332	12
2	0.8863	0.0415	0.1137	0.9585	0.8148	0.3428	0.6260	13
3	0.8998	0.1080	0.1002	0.8920	0.8331	0.3592	0.6435	11
4	0.9460	0.1161	0.0540	0.8839	0.9026	0.3613	0.6861	7
5	0.8497	0.2131	0.1503	0.7869	0.7689	0.3885	0.6167	15
6	0.7495	0.3828	0.2505	0.6172	0.6662	0.4475	0.5788	18
7	0.6917	0.2131	0.3083	0.7869	0.6186	0.3885	0.5266	21
8	0.3834	0.3683	0.6166	0.6317	0.4478	0.4418	0.4454	26
9	0.0000	0.6342	1.0000	0.3658	0.3333	0.577	0.4310	27
10	0.9229	0.0111	0.0771	0.9889	0.8664	0.3358	0.6542	10
11	0.9248	0.0680	0.0752	0.9320	0.8693	0.3491	0.6613	9
12	0.9730	0.1295	0.0270	0.8705	0.9488	0.3648	0.7152	6
13	0.9691	0.1982	0.0309	0.8018	0.9419	0.3841	0.7188	5
14	0.6840	0.2990	0.3160	0.7010	0.6127	0.4163	0.5342	20
15	0.7110	0.4717	0.2890	0.5283	0.6337	0.4862	0.5747	19
16	0.5183	0.2441	0.4817	0.7559	0.5093	0.3981	0.4648	24
17	0.5010	0.4418	0.4990	0.5582	0.5005	0.4725	0.4893	22
18	0.1541	0.6663	0.8459	0.3337	0.3715	0.5998	0.4628	25
19	1.0000	0.0316	0.0000	0.9684	1.0000	0.3405	0.7362	3
20	0.9923	0.0997	0.0077	0.9003	0.9848	0.3571	0.7337	4
21	1.0000	0.1765	0.0000	0.8235	1.0000	0.3778	0.7511	1
22	0.9923	0.2367	0.0077	0.7633	0.9848	0.3958	0.7492	2
23	0.7842	0.3480	0.2158	0.6520	0.6985	0.4340	0.5927	17
24	0.8651	0.5622	0.1349	0.4378	0.7875	0.5332	0.6858	8
25	0.5183	0.3904	0.4817	0.6096	0.5093	0.4506	0.4858	23
26	0.6802	0.6905	0.3198	0.3095	0.6099	0.6177	0.6130	16
27	0.1349	1.0000	0.8651	0.0000	0.3663	1.0000	0.6197	14

Table 7: Response Table for Grey Relational Grade

Level	Speed	Feed	Depth of Cut
1	0.5764	**0.6838**	**0.6283**
2	0.5861	0.6374	0.5903
3	**0.6630**	0.5043	0.6070
Delta	0.0867	0.1795	0.0381
Rank	2	1	3

6. ANALYSIS OF RESULTS

From Table 4 ANOVA for surface roughness, it is found that feed rate is the most significant factor among the three cutting parameters considered and contributes 71.11%, depth of cut is the next significant factor contributing

10.31%and speed is the least contributing factor.

Table 5 ANOVA for MRR, feed rate emerges as the dominating factor followed by the depth of cut and cutting speed. Feed rate contributes about 53.82 %, depth of cut contributes 25.62% and speed contributes 7.83% towards the material removal rate.

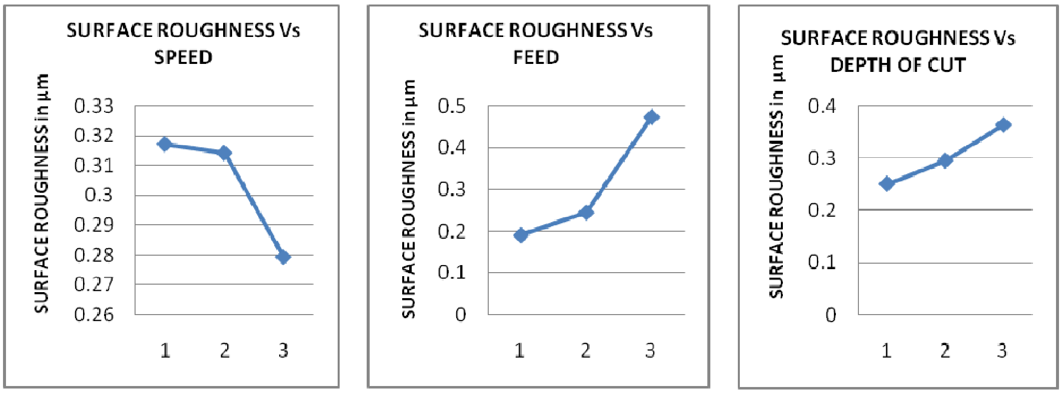

Figure 3: 2D Line Plot for Surface Roughness

Surface roughness values at 3 levels of speed, feed and depth of cut are plotted in Figure 3 and from the graph, the average surface roughness is minimum at higher speed 1800 rpm and maximum at lower speed 1200 rpm. Average surface roughness is minimum at lower feed 0.02 mm/revand maximum at higher feed 0.08 mm/rev. Average surface roughness is minimum at lower depth of cut 0.2 mm and maximum at higher depth of cut 0.7 mm.

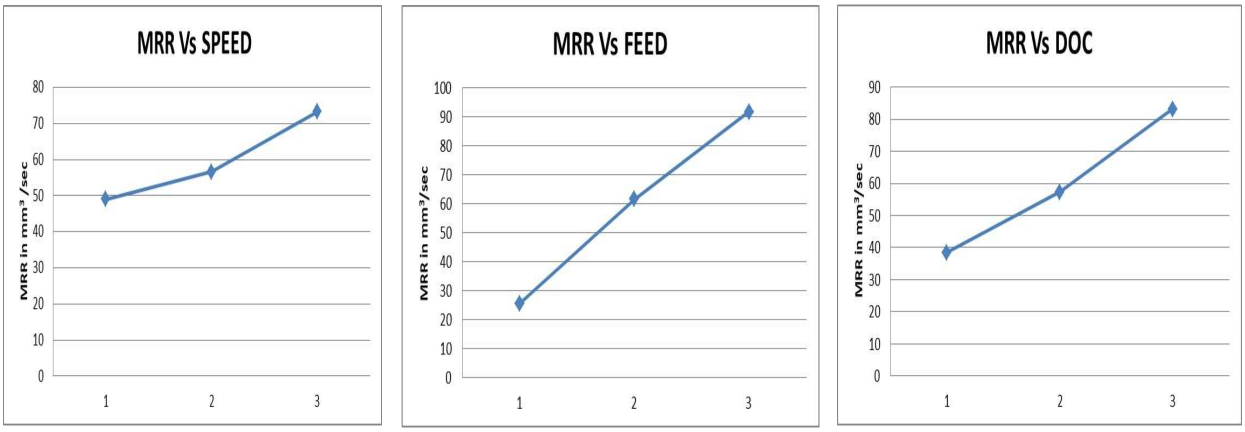

Figure 4: 2D Line Plot for Material Removal Rate

Average MRR values at 3 levels of speed, feed and depth of cut in Figure 4 and from the graph, the average MRR is minimum at lower speed 1200 rpm and maximum at higher speed 1800 rpm. The average MRR is minimum at lower feed 0.02 mm/rev and maximum at higher feed 0.08 mm/rev. Similarly average MRR is minimum at lower depth of cut 0.2 mm and maximum at higher depth of cut 0.7 mm.

Results of grey relational analysis are tabled in Table 6. In this analysis, the output responses surface roughness and material removal rate are assigned a weight of 0.6 and 0.4 respectively. From the table experimental run 21 gives the optimum result with Ra 0.162 µm and MRR 40.9492 mm^3/sec. Response table for grey relational grade is shown in Table 7. Andoptimum parameters for are maximum speed, minimum feed and depth of cut (A3B1C1).

7. CONFIRMATION TEST

A confirmation test is carried out at the optimal parameters speed 1800 rpm, feed 0.02 mm/rev and depth of cut 0.2 mm. Surface roughness is measured in the same way as followed in experiment and MRR is calculated as before. The results surface roughness 0.165 mm and MRR 20.026 mm^3/sec indicate that the optimal parameters produced better surface roughness.

8. CONCLUSIONS

Experiment on turning of oil hardened cold worked tool steel is carried out with TiN PVD coated aluminium carbonitride composite insert in wet condition. ANOVA is used to find the significant factors and grey relational analysis is applied to the data to get optimal cutting parameters. It is concluded that

- Feed is the most significant factor influencing surface roughness followed by depth of cut contributing 71.11% and 10.30% respectively.
- Cutting speed has the negative effect on surface roughness and is the least control over surface roughness.
- Feed is the dominating factor on surface roughness. Surface roughness varies directly with feed.
- Feed plays significant role in material removal rate. Other significant factors depth of cut followed by speed.
- From grey relational analysis parameters with A3B1C1 yields optimum results.

Many researchers stated that application of computational intelligence tools such as artificial neural network, genetic algorithm in optimization yielded better result [19].

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